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Trade-offs in maize seedling losses in African grasslands

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ABSTRACT

In central Cameroon, there are strongly defined savanna-forest boundaries. *Imperata cylindrica*, a pantropical Poaceae weed, is also one component of these savannas. There is a well-known discourse that *I. cylindrica* presence indicates poor soils and smallholder farmers report low crop establishment rates on land dominated by *I. cylindrica*. Yet, according to farmers one of the major limiting constraints is not soil fertility but seedling damage from birds, rodents and stem-cutting termites. It was hypothesised that losses might vary depending on both agronomic techniques used and vegetation management. In a two-factorial randomised complete block design, the effects of glyphosate herbicide clearance versus manual machete clearance and burning of plant residues versus mulching were assessed on *Zea mays* (maize) post-emergence seedling losses by birds, rodents and termites. Overall, birds caused greatest post-emergence losses in the first three weeks after planting (on average, 29%), followed by rodents (14%) and termites (11%). Glyphosate use significantly reduced seedling losses from birds (by 16%) suggesting that either birds avoided areas with lower vegetation cover or that such weedy vegetation is an attractant. For termites, glyphosate use significantly increased damage (13% damage in glyphosate plots compared with 8% in no-herbicide plots). Seedling damage by termites was greater in the burnt plots and where herbicide was applied. One compromise would be to avoid burning, so ensuring mulch cover to provide alternative food for termites, yet ensure vigorous weeding.

1. Introduction

Maize, *Zea mays* (L.) is the world's most important cereal crop with an estimated 1148 million tonnes produced in 2019 of which 82 million tonnes were produced in Africa (FAO 2019). Globally, 6–19% of maize yield is thought to be lost to animal pests, although weeds are considered the greatest cause of yield loss (Oerke 2006). More recently, Savary et al. (2019) estimated yield losses of maize to insect pests and pathogens to be 22.5% (19.5–41.1%) at the global scale. Mulungu (2017) highlighted the importance of rodents in causing yield loss in maize fields in Africa. Maize was considered by Hill (1997) to be the crop most susceptible to raiding by vertebrates in west Uganda. Swanepoel et al. (2017) conducted an Africa-wide systematic review on rodent pest research in smallholder farming systems. Of 125 studies on crop losses, 23 papers reported of losses at the seedling stage and these varied from 38 to 66% losses across crop species.

In West and Central Africa, there are strongly defined savanna-forest boundaries (Goetz et al., 2006). The humid forest and forest-savanna transition zones of West and Central Africa are characterised by high inter-annual variability in precipitation from 1500 to 1900 mm p.a. and thus is within the rainfall range identified by Hirota et al. (2011) where both forest and savanna can co-exist as alternative stable states. As human population densities increase, it has been predicted that increased land will be taken into agricultural production. These humid savannas, while having an albeit unique biodiversity, are less plant species-rich than adjacent forest. Preferentially cropping such areas would potentially create a win-win strategy to maintain agricultural productivity whilst reducing biodiversity and carbon stock losses. Yet cost-effective means would need to be developed to make such investments profitable to farmers and perceived losses would need to be controlled and mitigated against. Kekeunou et al. (2006), working along an intensification gradient in southern Cameroon, asked farmers to rank insects, vertebrate pests, weeds, crop diseases, and soil fertility by effect on crop yield. Farmers in all areas perceived that vertebrate pests were the most important agronomic constraint in annual food crop fields.

Observations in central Cameroon suggest the major rodents causing crop damage are cane rats and ground squirrels. The cane-rat family, Thryonomyidae, comprises just two closely related species, *Thryonomys swinderianus* Temninck and *T. gregorianus* Thomas, which are restricted to sub-Saharan Africa (Antoñanzas et al., 2004). In a groundnut experiment in central Cameroon, yield losses to rodents, predominantly African ground squirrels, *Xerus erythropus* Desmarest, were higher in plots

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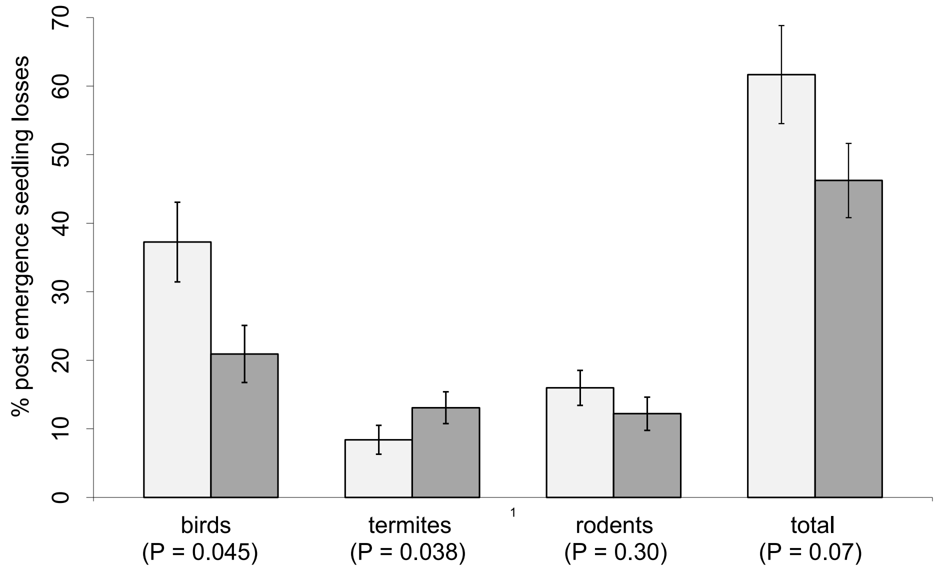

Fig. 1. Effects of glyphosate (dark grey bars) versus no herbicide (pale grey bars) use on post-emergence seedling losses (%) in the first three weeks after planting relative to initial planting density. Bars are standard errors of the means. P values give the significance of difference between herbicide and no herbicide treatments after log-sine square-root transformation (n = 12).

located near the centre of the savanna (47.8%) compared with near the forest edge (18.5%; Norgrove 2006). The higher rodent abundance in savannas, apart from the presence of the food source, grass, might be due to the absence of one of the main forest dwelling rodent predators, the mongoose *Herpestes naso*, for which rodents are the main vertebrate prey (Ray 1997). Potential rodent predators in these savannas include birds of prey, snakes, African civets (*Civettictis civetta* Schreber) and servals (*Leptailurus serval* Schreber), however, serval range is known to have declined in Cameroon so they may no longer be present locally (Kingdon 1984; Ray et al., 2005). However, relatively little research has been done on such rodents; in Swanepoel et al. (2017) systemic review, only nine papers each were found on crop losses to cane-rats and *Xerus* between 1910 and 2015.

A second challenge in cultivating grass-dominated land, particularly that with the noxious weed, *Imperata cylindrica* (L.) Raeusch., is how to clear such land without either provoking large-scale fires or inviting strong weed competition through regrowth during the crop phase. Using herbicide to clear fallow vegetation, rather than to control weeds during the crop phase, would have fewer negative health impacts. Yet, this would need to be profitable to be adopted in semi-commercialised smallholder farming systems.

The aims of this work were to: assess the level of post-emergence seedling losses of maize on humid savanna land; assess the effects of different commonly used agronomic treatments (mulching, burning and herbicide application) on losses; and, to differentiate between rodent, bird, and insect mediated losses. I hypothesised that losses and their relative importance might vary depending on both crop and vegetation management techniques used.

2. Methods

2.1. Establishment and treatments

The trial was conducted at Essong Mintsang village (N 04° 05′ E 11° 35’) in the Central Province of Cameroon. The site was a savanna with a mixed grass/sedge community dominated by *I. cylindrica*, *Andropogon gayanus* Kunth., *A. tectorum* Schumach. & Thonn, *Pennisetum purpureum* Schumach. and various Cyperaceae, with a sparse tree layer of predominantly *Bridelia ferruginea* Benth and *Annona senegalensis* Pers. The soil was an Ultisol (Tueche et al., 2013). The average annual rainfall is approximately 1570 mm year^{-1} in a bimodal distribution with rainy seasons typically lasting from mid-March to mid-July and from mid-August to end of November (Tueche et al., 2013). A short dry spell of approximately four weeks usually occurs in July and/or August. The main dry season lasts from December until mid-March.

The experiment had a two-factorial randomised complete design in six replicates with each factor at two levels: traditional manual clearance without herbicide (no herbicide) versus glyphosate application followed by manual cutting of dead stems (glyphosate); and burning versus mulching the grass residues. Plot demarcation was conducted in the short dry season (August) and plots were 10 m × 9.6 m. Herbicide plots were sprayed in mid-August, during the short dry season, with glyphosate at 2880 g active ingredient ha^{-1} in water delivered by using a knapsack (backpack) sprayer and full personal protective gear. No-herbicide plots were then manually cleared in early September. The dead stems in the glyphosate plots were cut at the same time. Residues were then left to dry then either burned in mid-September or distributed evenly in the plot as mulch. Plots were planted with open–pollinated yellow maize (sub-species mays c.v. CMS 8704) in the third week of September. Seeds were planted at 5 cm depth at an inter-row spacing of 80 cm and intra-row spacing of 50 cm, thus in 240 pockets (planting holes) per plot with two grains per pocket so a planting density of 50000 ha^{-1}.

2.2. Damage assessments

All pockets per plot were assessed at 1, 2 and 3 weeks after planting (WAP). Undamaged seedlings were counted and numbers of damaged seedlings attributed to birds, rodents or ants and termites were recorded. We estimated damage types following Johnson (1986), Key (1990) and F.A.O (2011). Plants were assumed to be damaged by birds if plants had been pulled out of the ground, and/or cut high or where bird prints were next to the plant. Plants were considered to have been damaged by rodents if seedlings had been dug out of the ground with digging signs visible and/or visible paw prints. Damage was attributed to termites if either damage was seen at the stem base or termites were observed near damaged plants.

2.3. Data analysis

Numbers of damaged seedlings were summed at 3 weeks after planting, calculated as a proportion per plot, log-sine square root

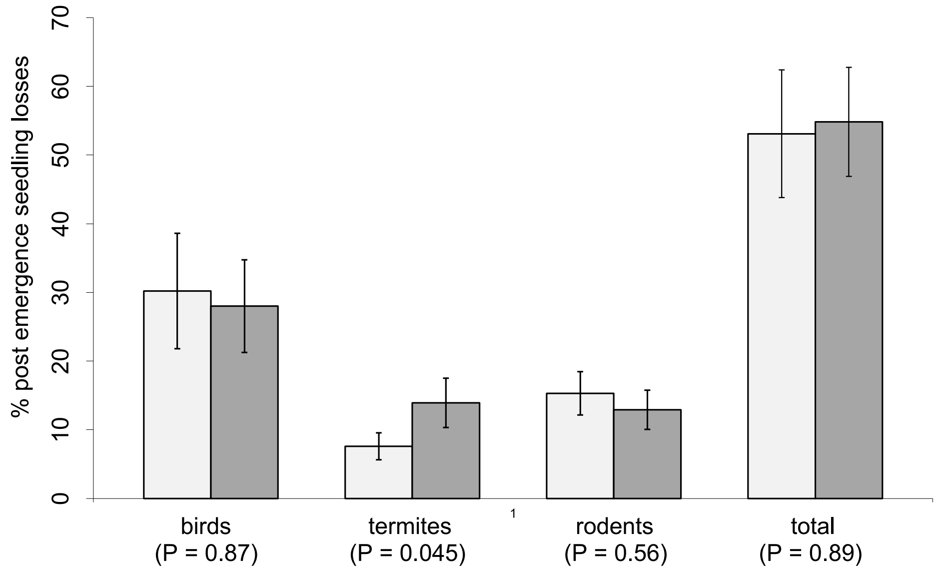

Fig. 2. Effects of burning (dark grey bars) versus mulching (pale grey bars) on post-emergence seedling losses three weeks after planting, relative to initial planting density. Data were analysed after log-sine square-root transformation, as is appropriate for proportions. Bars are standard errors of means. n = 12.

transformed prior to analysis in SPSS v22 using a two-level ANOVA, including the treatment interaction and a significance level of $P < 0.05$.

3. Results and discussion

Overall, birds caused greatest post-emergence losses in the first three weeks after planting (on average, 29%), followed by rodents (14%) and termites (11%; Fig. 1). Combined mean loss was 54%. There are few comparable data on post-emergence seedling losses. Olakojo (2001), comparing sites in the humid forest – savanna transition in Nigeria found that damage by birds, predominantly bush-fowl (*Francolinus bicalcaratus* L.), throughout the cropping phase to be 45% in the savanna compared with 28% in the high forest. Rodent damage was 36% in the savanna versus 10% in the high forest for another open-pollinated yellow variety. From outside Africa, pheasants alone damaged more than 50% of maize seedlings in an experiment in Germany (Esther et al., 2013). In a study in the Tropical Andes, birds were the main cause of maize seedling mortality at 2200 m altitude (Tito et al., 2018).

This study also confirms the importance of losses to rodents. Nearby, at the Northern side of the Dja forest reserve, farmers reported that cane rats damaged 73% of their fields, although there was no quantification within a field (Arlet and Molleman 2007). In Kenya, *X. erythropus* ground squirrels damaged approximately 10% of maize seedlings (Key 1990), being comparable in magnitude to our results. Similar results of maize seedling damage were reported from central Ethiopia (Bekele et al., 2003).

Glyphosate use significantly ($P < 0.05$) reduced seedling losses to birds (21% seedling losses compared with 37% in the no-herbicide treatment). Birds may avoid areas low in vegetation cover, to avoid being preyed upon. Alternatively, weedy fields may attract more bird damage. Vegetation regrowth was visually less in the glyphosate treatments (L. Norgrove, pers. obs.). In a similar study comparing glyphosate versus manual clearance, weed density at 4 WAP was 6.8 plants m^{-2} in glyphosate treated plots, compared with 12.0 plants m^{-2} in manually cleared plots (Norgrove, unpublished).

Two papers assessing the impact of vegetation structure on bird behaviour in the UK and in the Philippines, demonstrated that it may be species-specific, however, the papers were inconclusive (Horgan et al., 2017; Whittingham and Evans, 2004). Lal (1989), working in Nigeria, noted that maize seedling losses were higher in plots incorporating hedges, given that rodents and birds hid in the shrubbery and he also emphasized the importance of clean weeding. Alternatively, an experimental study on rice has demonstrated that birds are attracted to certain weeds and therefore weeds enhance damage from birds (Rodenburg et al., 2014). An observational study in a wheat field in Tanzania noted that greater damage was sustained in the weedier areas (Luder, 1985). In temperate USA, Bollinger and Caslick (1985) found that blackbird damage in maize fields was positively correlated with both their weediness and with the extent of hedges near the field. Thus, birds may both avoid low vegetation and be attracted to weedier fields, however, these hypotheses need further investigation.

On the contrary, there were less ($P = 0.038$) post-emergence seedling losses attributed to termites in no-herbicide (8%) compared with glyphosate (13%) treatments. There were no detectable effects on rodents ($P = 0.30$). Overall, there was no significant difference in total post-emergence seedling losses between glyphosate and no herbicide treatments ($P = 0.07$; Fig. 1).

Post-emergence seedling losses to termites were significantly higher ($P = 0.045$) with burning (13.9%) rather than mulching (7.6%; Fig. 2). There were no significant effects on losses to birds ($P = 0.87$) nor to rodents ($P = 0.56$). Both glyphosate application and burning would reduce living vegetation. Furthermore, burning would also reduce leaf litter. Both processes may therefore increase the risk of crops being attacked by termites. While termite attack of maize seedlings is reportedly rare (Wood et al., 1980), certain genera have been observed to attack seedlings (Van den Berg and Riekert, 2003). In Uganda, mulch reduced maize seedling damage by Microtermes, Macrotermes and Pseudacanthotermes (Sekamatte et al., 2001). This supports the hypothesis that mulch provides alternative food for termites, reducing their attack on crops.

4. Conclusion

Greatest post-emergence seedling losses were attributed to birds although glyphosate use reduced these losses. This may be because such birds both avoid areas with less vegetation and, on the contrary, they are attracted to weedier fields. Such differences would probably be greater in larger scale experiments given larger areas with sparse vegetation. While post emergence seedling loss attributed to termites was higher in glyphosate than non-herbicide treatments, the overall impact of ants and termites was less important. This difference could be mitigated by maintaining mulch in the plots and thus providing an alternative food source to living plants. Conversely, burning the grass residues greatly accentuated losses to such insects so should be avoided.

Declaration of competing interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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